Seven-Function Systems Multimeter Offers Extended Resolution and Scanner Capabilities

This new 3½-to-6½-digit DMM measures frequency and period as well as dc and ac voltage, dc and ac current, and resistance. Extended resolution provides an extra digit.

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A NEW DIGITAL MULTIMETER (DMM), the HP 3457A Multimeter (Fig. 1), is designed to provide both bench and systems users with the highest possible performance and the maximum measurement versatility consistent with a very competitive price. System features such as an easy-to-use multimeter language, programmable front and rear input terminals, and front-panel access to virtually all of the HP-IB (IEEE 488/IEC 625) commands for convenient test program debugging, help improve throughput in automatic test system applications. Reading rate, an important parameter for a systems multimeter, can be traded off with measurement resolution.

In the HP 3457A, more than 1300 readings per second can be converted to ±3000 counts, or more than 1200 readings per second can be converted to ±30,000 counts with a 100-μs sample aperture. For measurements where rejection of 50 or 60-Hz noise is critical, 53 readings per second can be converted with 0.33-ppm resolution. More noise attenuation can be achieved by further slowing the conversion rate, still maintaining greater than 160 dB of effective common mode noise rejection.

For applications requiring precise measurement pacing, the HP 3457A lets the user set the interval between multiple readings taken from a single trigger. This internal timer capability is particularly useful for waveform sampling and digitization. The timer is settable to 0.02% accuracy in 1-μs increments. This function is performed by the system microprocessor, and jitter on the timer interval is limited to a negligible 2 ns.

The ability to reprogram the multimeter rapidly is an important consideration for a systems instrument. In situations where the multimeter is used with a scanner, it is common to require a different function and range for each channel. The HP 3457A has a special programming mode for these applications, enabling it to change function and range and take a reading up to 30 times per second.

The HP 3457A offers seven functions: dc and ac voltage, dc and ac current, resistance, frequency, and period. The 24-hr dc accuracy on the 3V range is ±5.5 ppm. To broaden the range of applications, several functions have a greater measurement capability than is normally found in similar instruments. For example, resistance measurements can be made to 3 GΩ and useful dc current measurements can be made down to 100 pA. The ac voltage function has full-scale ranges as low as 30 mV and is specified to 1 MHz.

The HP 3457A's 2000-byte internal memory can be partitioned between reading, subprogram, and state storage. In addition, up to 11 complete setups can be stored in a nonvolatile state memory for easy reconfiguration.

Statistical functions such as mean and standard deviation are part of the built-in math routines. Other routines include thermistor linearization, pass-fail limit testing, dB, dBm, scale, offset, and single-pole digital filters. The rms math function aids low-frequency ac voltage measurements.

The HP 3457A is programmable via the HP-IB. A **VOLTMETER COMPLETE** output and an **EXTERNAL TRIGGER** input are useful for synchronizing other test instrumentation with the DMM. The HP 3457A also features a set of new easy-to-use program commands that will allow today's software to be used with tomorrow's DMMs. The commands form a core language called HP-ML (HP Multimeter Language).

Autocal

Two HP 3457A functions, ac volts and the 3-GΩ resistance ranges, use an autocalibration feature to improve their accuracy under changing environmental conditions. This feature, which requires no external standards, can be ini-

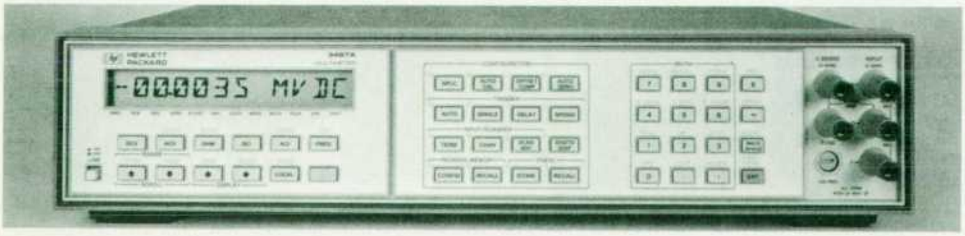

Fig. 1. *The HP 3457A Multimeter is designed for both bench and systems use. Reading rate can be traded off with measurement resolution. Seven functions provide versatility.*

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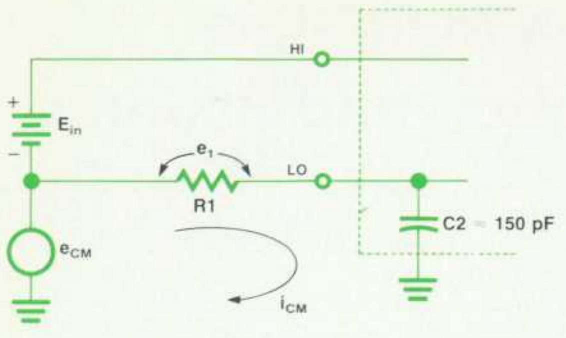

Fig. 2. *Common mode current flow in a floating voltmeter such as the HP 3457A.*

tiated from the front panel and is also programmable. Autocal corrects both gain and offset errors for the extended ohms function. In the case of the ac functions, Autocal recompensates the input attenuator for flat frequency response and nulls out dc offsets in the input amplifier for better dc accuracy. However, it does not correct for midband gain changes. This must be done using the electronic calibration process along with an external standard.

Noise Rejection

An important consideration in making precision measurements is the effect of power-line-related noise on the measurement. An unwanted noise voltage, shown as e_1 in Fig. 2, can result from a 50-Hz or 60-Hz voltage that is common to both input leads. This occurs because of a voltage divider action between the impedance from instrument **LO** to ground (C2) and the resistance in the **LO** input lead, R1. Guarding is one way to reduce the effect of the **LO**-to-ground impedance.[1] In a guarded voltmeter, an additional sheet-metal structure is placed between the analog circuitry and chassis ground. It is almost unavoidable that the capacitance between this shield and the chassis is very large, on the order of 1000 to 2000 pF. When the guard terminal is used properly (Fig. 3a), this large capacitance is not a serious problem since the noise current does not flow through the measurement loop. However, the most common arrangement is to leave the guard connected directly to the **LO** terminal. For example, this may be necessary when scanning several signals that do not have a common guard point. This situation is commonly encountered in data acquisition applications. Unfortunately, connecting the guard to **LO** causes the large guard-to-ground capacitance to appear between ground and **LO**. Fig. 3b depicts this situation; the **LO**-to-ground capacitance is approximately ten times larger than it would have been without the guard. In this case, the noise voltage e_1 is also ten times larger than it would have been without the guard.

In the HP 3457A, considerable thought was given to minimizing the stray capacitance from the isolated analog measurement section to chassis ground. The result is a typical capacitance of 150 pF. Referring to Fig. 2 and using C2 = 150 pF and R1 = 1 kΩ, the effects of e_{CM} are reduced by about 86 dB at 60 Hz. Thus, low capacitance to ground allows the HP 3457A to have very good rejection of ac common mode signals even though it is not fully guarded. The inherent normal mode rejection of an integrating voltmeter further improves this performance. For example, with a 10-PLC (power line cycle) integration time, the effective common mode rejection ratio (the sum of ac common and normal mode rejection) is 156 dB. This means that a 50Vac, 50 or 60-Hz common mode voltage will only result in 1 μV of noise when integrating over ten PLCs.

High-Resolution Mode

While the front-panel can display 6½ digits (± 3,000,000 counts), a seventh digit is available. This extra digit is continuously written into a math register when using the longer integration times (10 or 100 PLC). To access the seventh digit over the HP-IB, the user can recall the high-resolution math register (HIRES). Since this register is already scaled, it can be added directly to the current reading to get a 7½-digit measurement. Fig. 4 shows typical 3V-range noise for 7½-digit readings.

Scanner Options

To add versatility, the HP 3457A has provisions for field-installable input multiplex options. Two different cards are available, an armature relay multiplex card and a reed relay multiplex card. The HP 44491A armature relay multiplex card (Fig. 5) offers eight two-wire channels that can be configured from the front panel or under program control as four four-wire channels (for resistance measurements) or any combination of four-wire and two-wire inputs. The input channels have a maximum switching and measurement speed of 33 channels per second. Two other channels

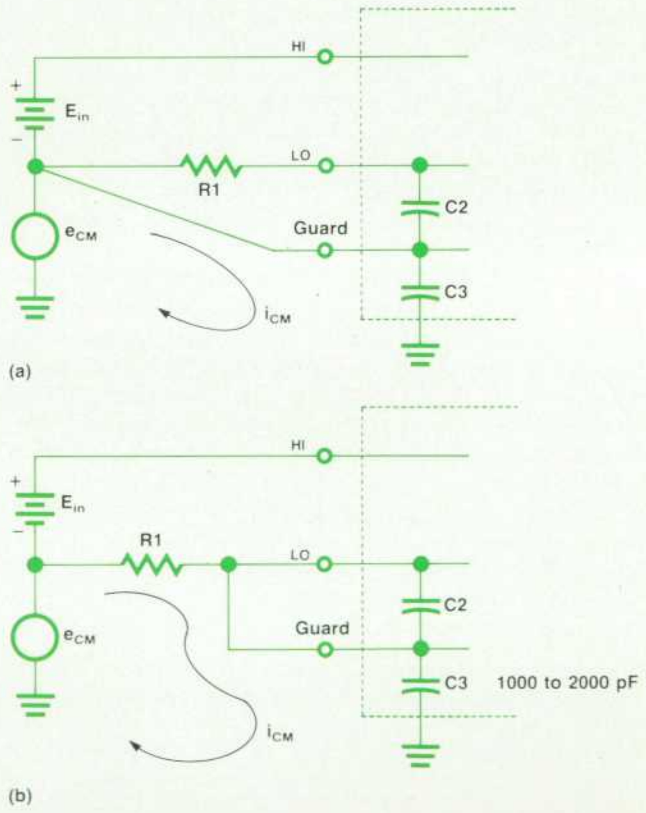

Fig. 3. *(a) The correct way to connect the guard terminal to shunt the common mode current away from the* **LO** *lead. (b) The most commonly used guard connection.*

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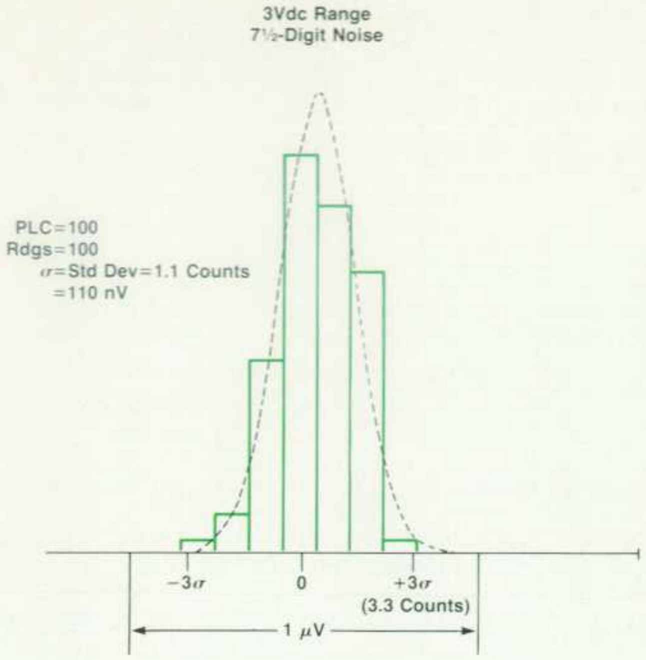

Fig. 4. *Histogram showing typical HP 3457A seventh-digit noise performance.*

are available that can be configured as either ac or dc current inputs or as actuators able to switch 1.5A at 250Vac or 1.5A at 30Vdc.

The HP 44492A reed relay multiplex assembly offers ten two-wire channels able to switch up to 125V peak at a rate of 300 channels per second (see Fig. 6).

Analog-to-Digital Converter

System DMMs must meet stringent measurement requirements and provide great flexibility. HP's Multi-Slope II conversion technique[1] is unequaled in its ability to respond to these needs. Speed, resolution, and noise rejection can be traded off as the measurement situation dictates.

Development of the analog-to-digital converter (ADC), and indeed of the entire instrument, relied upon the use of available, proven technology that could be adapted or enhanced to meet our needs. Multi-Slope II conversion is implemented using the hybrid converter hardware developed for the HP 3468A and 3478A Multimeters.[2] All of the fundamental integrator reference (slope) currents are provided by the hybrid. MOS switches for current source selection and some control logic are also included in the hybrid. Enhancements to the analog and digital hardware along with refinements to the measurement algorithms account for most of the HP 3457A's increased measurement speed and resolution.

Fast decision times are critical to increasing both conversion rate and measurement resolution. An 8051 microcomputer controls both the measurement setup and the ADC. Clocked at 12 MHz, the 8051 allows the ADC hardware to run at 2 MHz. The 0.5-μs cycle times and rich instruction set of the 8051 allowed us to realize a significant improvement in decision times. The 8×8 hardware multiply allowed the measurement calibrations to be overlapped with the conversion, yielding further speed improvements.

Although the HP 3457A uses the same ADC hybrid as the HP 3478A, the similarities stop there. The converter is actually closer to that of the HP 3456A[3] with some hardware enhancements. To improve decision times further, logic external to the microcomputer was added. Part of the counting and Multi-Slope II run-down slope control functions were offloaded from the microcomputer. To maximize conversion speed it is critical to spend a minimum of time in run-down. Run-down is the interval after the input voltage has been integrated (see Fig. 7). To minimize run-down time, it is important not to permit the integrator to overrun a zero crossing too far. Every microsecond of overshoot will require 10 μs at the next smaller slope (1/10 the previous slope) to return to zero. To involve the microcomputer in these zero-crossing decisions would quickly add tens of microseconds to the run-down conversion time.

The input voltage is integrated during the run-up phase of the conversion cycle (see Fig. 8). Unlike dual-slope conversion, Multi-Slope II actually starts converting the answer in the run-up phase. For the run-up interval, the 8051 microcomputer has active control of slope decisions. Slopes in run-up are quantized in fixed increments of time and the 8051 keeps track of the total time spent in each slope direction. During run-down, however, the slope control is performed by synchronous logic clocked by the same 2-MHz signal as the time interval counter (see "Frequency

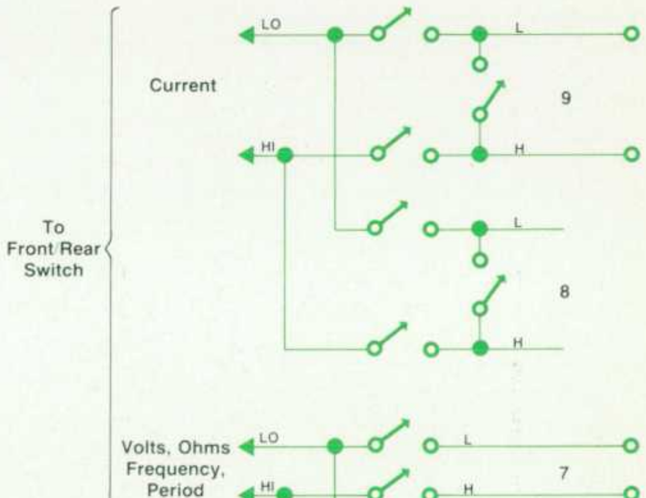

Fig. 5. *HP 44491A Armature Relay Multiplexer schematic diagram.*

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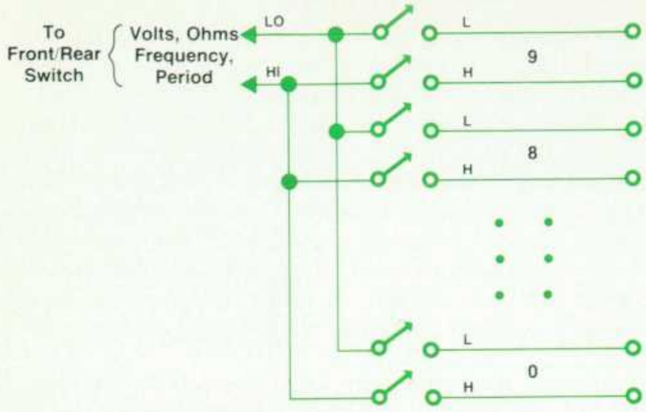

Fig. 6. *HP 44492A Reed Relay Multiplexer schematic diagram.*

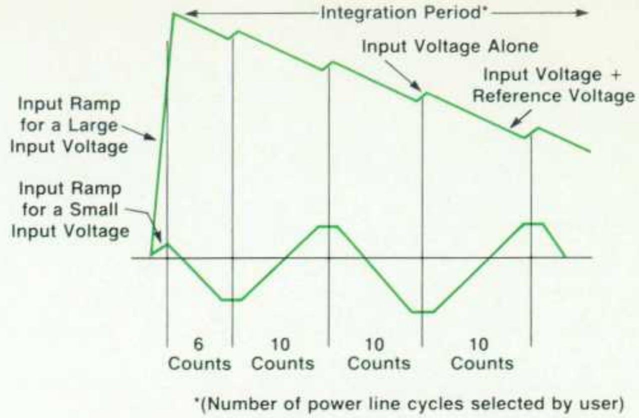

Fig. 8. *During the integration time used in the Multi-Slope II method, the reference voltage ramp is applied periodically at a fixed rate independent of the unknown input voltage level. The polarity of the reference ramp during each period is dependent on the value of the sum of the previous ramp and the input voltage just before the previous ramp was turned off. This approach reduces the voltage level at the end of the integration time, thus reducing the demand on the integrator capacitor for low dielectric absorption. The number of positive reference ramps used during the integration time minus the number of negative ramps determines the most-significant digits of the reading.*

Counter Technique," page 19). Slope times are accumulated in a 20-bit counter enabled selectively from several sources as needed. The time interval counter consists of one of the microcomputer's internal 16-bit counters prescaled by a microcomputer-readable external 4-bit counter clocked by a phase-stable 2-MHz signal. Thus, the run-down slope times are quantized and measured in 0.5-μs increments, and a minimum of slope overshoot is maintained. Initiation of a run-down slope and the selection of the slope magnitude are still performed through microcomputer intervention. After completion of each run-down slope, the external counter is read by the 8051 and the result is accumulated with the appropriate scale factor. Run-down converts the three least-significant internal ADC digits with a total measurement overhead of only 150 μs.

As previously mentioned, the HP 3457A's ADC is very similar to that of the HP 3456A. It was necessary to increase the speed of the analog circuitry to support operation at the higher conversion rates. Less time is allowed for circuit settling, so error sources had to be minimized. A primary source of ADC dynamic error is dielectric absorption from the integrator capacitor. This can be a limiting factor in

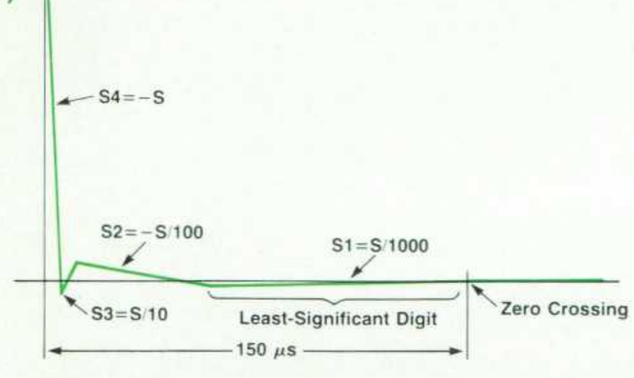

Fig. 7. *The Multi-Slope II A-to-D technique used in the HP 3457A DMM uses four slopes during the rundown period to determine, in succession, the four least-significant digits of the final reading.*

ADC linearity. The Multi-Slope II algorithm is intrinsically a zero-seeking process, but it still yields an average integrator voltage proportional to the input. Although Multi-Slope II is much less sensitive to such effects than other conversion techniques, dielectric absorption can still introduce linearity errors. The HP 3457A incorporates a new technique to minimize this error. A compensation circuit forces the average voltage on the integrator to approach zero more closely for all inputs. Dielectric absorption then becomes of only secondary importance. A total measurement linearity error (ADC and input conditioning) less than 1 ppm of range is typical. Remaining nonlinearities are caused by resistor self-heating effects, which are tightly controlled through a fine-line resistor process (see next section). Precision current sources are produced using extremely stable HP resistor networks. All ADC performance is achieved without the use of mechanical adjustments or selected component values. Thus linearity of the DMM is virtually unchanged by exposure to any specified environmental conditions.

Long-Term Stability

Long-term accuracy of a DMM is fundamentally limited by three sources of error: the ratio stability of critical resistors, the stability of calibration adjustments, and the long-term drift of the instrument's voltage reference. In a real environment, significant errors may be produced through exposure to vibration, temperature cycling, or humidity changes, conditions prevalent in many system environments.

The HP 3457A uses an HP fine-line resistor process which exhibits extremely low long-term drift. Resistors from this process are used in all critical applications. The resistors of the ADC and input signal conditioning sections that can contribute to long-term drift are examples. Another

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